Journal of Cleaner Production 189 (2018) 108–115

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Evaluation of socio-economic factors on CO_2 emissions in Iran: Factorial design and multivariable methods

Nasibeh Hajilary [a], Aref Shahi [b], Mashallah Rezakazemi [c, *]

[a] Department of Chemical Engineering, Golestan University, Gorgan, Iran
[b] Department of Chemical Engineering, Petroleum University of Technology, Abadan, Iran
[c] Faculty of Chemical and Materials Engineering, Shahrood University of Technology, Shahrood, Iran

ARTICLE INFO

Article history:
Available online 10 April 2018

Keywords:
CO_2 emissions
Energy
Climate change
Latent variable method
GDP
FDI
Citizen rate

ABSTRACT

Nowadays, global CO_2 emissions play a focal role in the human sustainable development and environmental concern. This paper investigates the relationships among CO_2 emissions and the efficient factors including energy consumption, oil product, gross domestic product (GDP), non-oil GDP, foreign direct investment (FDI), gas consumption, citizen rate, cost of energy, number of vehicles, and mean incoming urban and rural in Iran over the period of 1976–2016. A factorial design was applied to screening the significant factors and their relations on Carbon emissions. The results indicated that energy consumption and its cost, citizen rate, non-oil GDP, and FDI have significant effects on CO_2 emissions and there is a linear relationship among these factors and CO_2 emissions. The relationships among significant factors were evaluated for the first time by the latent variable modeling method using partial least square (PLS) model. The latent variable model results showed that the lower energy consumption leads to lower CO_2 emissions with a coefficient of 0.87. The results also indicated that citizen rate positively and FDI negatively (the share of 13% and 4%) are the other most important factors in raising CO_2 emissions by a directional relationship. The share of energy cost and non-oil GDP in explaining CO_2 emissions is minimal. It was found that the chance of successful determination of critical factors on CO_2 emissions increases with these mathematical models.

1. Introduction

Nowadays, global warming has been a main challenge in the world (Rezakazemi et al., 2011, 2014, 2017, 2018). The consequence of these phenomena is so severe that a world determination is necessary and some researchers and politicians have performed in this regard (Razavi et al., 2016; Shirazian et al., 2011; Soroush et al., 2017). In this regard, Kyoto protocol (1992), Doha Amendment to the Kyoto protocol (2012), and the Paris agreement on climate changes (2015) are some of the results of these efforts which have forced state parties to reduce greenhouse gas (GHG) emissions. GHG emissions, resulting from the burning of large amounts of fossil energy, plays a key role in the global warming and climate instability (Friedlingstein et al., 2014). The consumption of fossil fuel has risen more than six times during 30 years (from 1967 to 2007). Also, the share of carbon dioxide (CO_2) in GHG emissions is 58.8% (Lotfalipour et al., 2010).

Up to date, numerous studies have been carried out on effective parameter may have significant effects on CO_2 emissions in different countries (Hoffmann et al., 2005). The first group of researchers has focused on the hypothesis of environmental Kuznets curve (EKC) (Farhani et al., 2014a). The EKC indicates that CO_2 emissions increase with increasing the income level until a certain turning point reaches. This means that CO_2 emissions can be determined as a function of per capita income, which presumes a unidirectional causality link between income and CO_2 emissions. The main problem of these studies is that they suffer from its lack of feedback from environmental pollutants to economic output (Coondoo and Dinda, 2002; Dinda and Coondoo, 2006). Coondoo and Dinda (Coondoo and Dinda, 2002; Dinda and Coondoo, 2006) found that the relationship between CO_2 emissions and the level of income may be changed based on the diagram of EKC in different countries. Ahmad et al. (2017) examined the EKC hypothesis using autoregressive distributed lag (ARDL) approach for Croatia in long

* Corresponding author.
E-mail addresses: mashalah.rezakazemi@gmail.com, rezakazemi@shahroodut.ac.ir (M. Rezakazemi).

https://doi.org/10.1016/j.jclepro.2018.04.067
0959-6526/

run and showed a bidirectional causality between CO_2 emissions and income while a unidirectional in vice versa.

The second group of researchers has concentrated on the relation among CO_2 emissions, income, and energy consumption (Mazandarani et al., 2011; Soytas and Sari, 2006; Soytas et al., 2007). In this area, Soytas et al. (Soytas and Sari, 2006; Soytas et al., 2007) studied the relevance between energy consumption and income by accepting the fact that CO_2 emissions are remarkably generated by the use of fossil fuels. Alam et al. (2012) revealed two-way causality between CO_2 emissions and energy consumption for Bangladesh. There is a similar study for Malaysia indicating that these factors have a positive relationship in long-run (Ang, 2008). Menyah and Wolde-Rufael (2010a) depicted that there is a Granger causality between energy consumption and CO_2 emissions by considering nuclear energy consumption by applying a modified Granger causality vector error correction model. Soytas et al. (2007) showed that there is not a Granger causality between income and CO_2 emissions in the USA while a Granger causality link exists between energy use and CO_2 emissions in long run.

The third group of researchers has discussed the effect of foreign direct investment (FDI) on environmental pollution. Positively, multinational companies (MNC) are advanced and cleaner technologies in comparison with the host countries. When the environmental regulations are not taken seriously in the host countries, MNCs are interested to relocate the polluting industries in developing countries (Xing and Kolstad, 2002; Zarsky, 1999). In this area, Merican et al. (Merican, 2007) found that there is a positive link between FDI and CO_2 emissions in Malaysia, Thailand, and the Philippines and has a negative effect in Indonesia by employing the ARDL model. Also, in another study, they revealed a two-way causality from emissions to FDI and unidirectional causality from output to FDI in Brazil, Russia, India, and China using multivariate Granger causality method (Ang, 2007; Pao and Tsai, 2011). Economically developed countries in comparison with developing countries need more energy while they use energy more efficiently; hence, the link between the energy consumption and CO_2 emissions comes up with mixed conclusions (Xing and Kolstad, 2002; Zarsky, 1999).

The fourth group of the researchers has investigated the relations among CO_2 emissions, economic development, and energy consumption (Alshehry and Belloumi, 2015; Menyah and Wolde-Rufael, 2010b; Ozcan, 2013; Wang et al., 2016). For example, Chang (2010) showed both gross domestic product (GDP) and energy consumption (in four different types including crude oil, natural gas, electricity consumption and coal) cause more CO_2 emissions in China. In a study performed in France, researchers found that directional relations among CO_2 emissions, economic growth, and energy consumption (Ang, 2007). Wang et al. (2016) revealed a bidirectional causality between energy consumption and GDP through both linear and nonlinear causality test, respectively.

The fifth group of the researchers has used a multivariate framework to examine the causal links among more variables such as CO_2 emissions, energy consumption, economic growth, FDI, and population (Kasman and Duman, 2015; Merican, 2007). For example, Menyah and Wolde-Rufael (2010b) conducted a study for Sub-Saharan Africa and found that there is a long-term relationship among energy consumption, CO_2 emissions, and economic growth and also, unidirectional causality long-run from energy consumption to economic growth. The results also showed that there is not a clear relationship between FDI and CO_2 emissions and there is a unidirectional Granger causality relationship among the variables. Alshehry and Belloumi (2015) employed a Johansen multivariate cointegration approach to examine the causal link among CO_2 emissions, energy consumption, energy price and economic development in Saudi Arabia. They found a unidirectional long-run causality from energy consumption to economic output and CO_2 emissions. Furthermore, the results showed unidirectional causality from CO_2 emissions to energy consumption and economic growth, and also between energy prices to CO_2 emissions in the short term. Kasman and Duman (2015) employed root test, panel co-integration approach and causality tests to study the relationship among energy consumption, CO_2 emissions, economic development, trade openness and urbanization for European Union member. The results showed that there is an inverted U-shaped between CO_2 emissions and income. The results also confirmed that underlying variables except urbanization have a statistically significant effect on the long-run equilibrium. In another study performed by de Freitas and Kaneko (de Freitas and Kaneko, 2011) in Brazil, CO_2 emissions increase with increasing GDP and population.

Although Iran is one of the greatest countries of the holder of hydrocarbons and CO_2 production, there are few studies that examine the mentioned factors in CO_2 emissions in Iran. For instance, CO_2 emissions up to 2035 in Iran were predicted using ant colony optimization through the linear and nonlinear equations (Samsami, 2013). Zamani (2007) reported a long-run unidirectional link from GDP to total fuel consumption and bidirectional relationship between GDP and gas consumption and also between GDP and petroleum products consumption. In another study in Iran, Lotfalipour et al. (2010) showed a three unidirectional Granger causality running between (i) GDP and CO_2 emissions, (ii) between consumption of petroleum products and CO_2 emissions, and (iii) between natural gas consumption and CO_2 emissions.

However, from surveying literature, it can be realized several factors including energy consumption, energy price, energy types, FDI, GDP, economic growth and gas consumption have significant effects on CO_2 emissions and few studies have been individually carried out in the evaluation of these effective parameters on CO_2 emissions. Most of these studies are limited to considering two, three or at last four factors and do not consider all of the mentioned factors together. Besides that, there are some other effective parameters which are as significant as the one which is sought but no investigations have been conducted. These effective parameters are citizen rate, non-oil GDP (for country related to the oil economic), incoming urban and rural, and a number of cars which were evaluated together with those previously recognized parameters for the first time in this study. However, the main objective of this paper is to investigate the relationships among these dependent variables have effects on CO_2 emissions altogether. Also, a comprehensive review on the status of energy in Iran was performed. First, their relations were determined based on available data for Iran over the period of 1976–2016 using factorial design. Second, the effects of significant factors, for the first time, were evaluated using the latent variable model and the functional relationship that linked these factors to CO_2 emissions was determined by the latent structure/partial least square (PLS) model. None of the previous studies, to the best knowledge of authors, have published using latent variable model for CO_2 emissions. The results provided in this study can be generalized to other countries for making better policy to CO_2 emission reduction. The proposed method has also potential to solve omitted variables bias problem that other literature faced. Indeed, there are few studies on CO_2 emissions in Iran which are limited to the evaluation of a few parameters and limited years while emissions is a challengeable issue and many variables are involved. Also, the approaches for evaluation of these variables are not appropriate and precise and the causality relation of parameters on each other have not considered. This paper has tried to fill these lacunas.

2. Overview of energy in Iran

According to British Petroleum Statistical Review of World Energy, Iran is the world's largest holder of proved gas reserves (1136.1 trillion cubic feet) and also the world's fourth-largest holder of proved oil reserves (21.7 thousand million tons). CO_2 emission has increased about 600% during 30 years from 1965 to 2005. Although Iran has joined to the Tokyo Protocol, CO_2 emissions per capita increased 41.9% during ten years from 2006 to 2016. These data show that the slope of increasing CO_2 emissions has decreased significantly. However, more effort should be made in this regard. The energy types' consumption during 2005–2015 in Iran is reported in Table 1. The primary energy sharply increased by about 50% in Iran during the period of 2005–2015. As can be seen, Iran has the largest growth in consumption of natural gas and few significant increases in consumption of nuclear energy during 2005–2015 was observed. Also, the oil consumption has not significantly increased during ten years because oil is replaced natural gas, especially in the domestic and industrial usages. Nuclear energy, as well as hydroelectricity, has slightly increased while coal consumption has reduced.

In case of renewable energy, Iran has abundant of solar and geothermal energies consumption but wind energy will account for 3% of the country nominal electricity generation capacity. The required electricity of Iran is almost provided by fossil fuel. 55.9 and 43.5% of Iran's electricity came from natural gas and oil, respectively (Iran's energy balance annually, Office of Energy and Power Affair). Fig. 1 shows the distribution of energy consumption in different parts of Iran. About 36% of total energy consumption was used by the household sector. The industry and transport sectors have the similar share of total energy consumptions and accounted for 25% of total energy consumption in 2016.

Since Iran is a country with high rate of electrical consumption and having good potential of renewable energy sources especially in the wind and solar energies, using renewable energy to produce electrical energy helps to sustainable developments (Mazandarani et al., 2011). According to the statistical, 10383.1 MW of electrical energy is produced from renewable energy. Also, it is expected the share of electricity production from these sources will increase in near future because of the encouraging governmental policy; Iran's government has a project to purchase electricity from the private sector if produced from renewable energy.

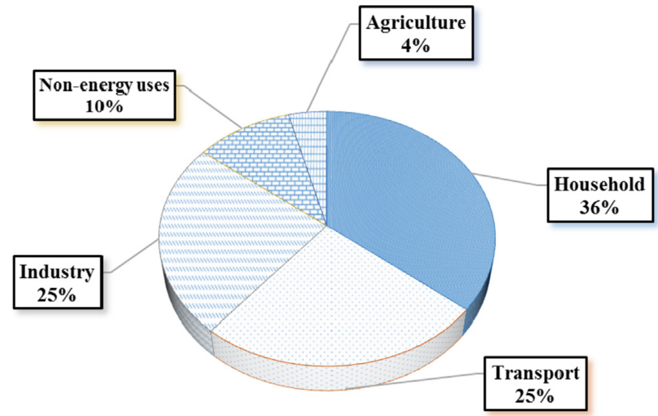

Fig. 1. Distribution of energy consumption in different sections in Iran.

3. Data and methodology

3.1. Data

The annual data used in this study includes eleven variables over the period of 1976–2016 in Iran. The GDP without considering oil export (non-oil GDP) and GDP with considering oil (million Rials), natural gas production (measured in million cubic meter (MCM)), oil production (million liters), mean of incoming urban (thousand Rials), mean of incoming rural (thousand Rials), energy consumption (measured in million-barrel oil), number of vehicles, cost of energy (thousand Rials to barrel oil), FDI (Billion USD), and CO_2 emissions (metric tons) were obtained from the National Accounts of Iran. CO_2 emissions data were obtained from the International Energy Agency, IEA statistics, Edition 2016.

3.2. Methodology

To evaluate the effects of each eleven variables on CO_2 emissions, at first, statistical design approach was chosen based on a factorial design in order to screen the significant parameters. The statistical design approach can be also used sequentially to refine and model a process. The two-level fractional design was first used in this study to explore and screen all variables to find which variables have significant effects on CO_2 emissions. The maximum and minimum values of each eleven variables in the periods of 1976–2016 were respectively selected as high and low values for two-level fractional factorial design. This is referred to as 2^k designs where k represents the number of factors being evaluated. In a factorial design, the statistical models are validated by fitting the actual responses into prevailing linear and two-factor interaction models. The mathematical model is presented below:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i<i<j}^{k} \beta_{ij} x_i x_j + \varepsilon \tag{1}$$

where y is the response, β_i and β_{ij} are linear and interactions terms, respectively. $x_i x_j$ denotes the multiply of binary variables, and ε is the statistical random error term. This model involves the linear influence of the independent factors and interactions among variables. The disadvantage of this model is that it does not estimate the quadratic relations. Therefore, the two-level factorial design has

Table 1
Energy type's consumption (million barrel of oil equivalent) in Iran during 2005–2015.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Oil	80.5	87.7	89.6	93.1	95.4	86.8	88.0	89.0	95.5	93.1	88.9
Natural gas	2.5	100.8	113.0	119.9	128.4	137.6	146.0	145.4	146.6	162.0	172.1
Coal	1.6	1.5	1.6	1.2	1.4	1.3	1.4	1.1	1.2	1.2	1.2
Nuclear energy	–	–	–	–	–	–	[a]	0.3	0.9	1.0	0.8
Hydroelectricity	3.0	4.2	4.1	1.7	1.5	2.2	2.4	2.8	3.4	3.4	4.1
Renewable energy	[a]	[a]	[a]	[a]	0.1	[a]	0.1	0.1	0.1	0.1	0.1
Primary energy	177.5	194.2	208.2	215.9	226.7	227.8	237.9	238.6	247.6	260.8	267.2

[a] Less than 0.05%.

limitation to linear dependence but it can be used for theoretical screening of factors. The independent variables in the model design are presented in Table 2.

In the second step, to evaluate the effect of significant factors which were determined by two-level factorial design, the multivariate latent variable method using PLS was applied. The modeling of the latent variable was performed using ProSensus Multivariate (ProMV) version 12.08 (ProSensus Inc.). This model provides an appropriate tool to handle all data including linear and nonlinear relations and highly collinear and noisy data (Eriksson et al., 1999). Also, this method handles the highly correlated nature of the multivariate data by projecting the data into lower dimensional, orthogonal space and does not need to prejudge the variable for applying the methods. The PLS regression can model both X and Y spaces and can offer casualty model in the low dimensional latent variable spaces (MacGregor et al., 2015; Yacoub and MacGregor, 2004). The PLS model maximizes the covariance of X and Y. By moving in latent variable space (T[1], T[2], …), the causal effects of these moves can be predicted on X and Y through the X and Y space models.

4. Results and discussion

4.1. Statistical analysis

According to the fractional factorial design, CO_2 emissions, F-value, P-value, and degree of freedom were calculated and the results are reported in Table 2. By substituting the coefficients in Equation (2) (the parameters of Equation (2) are shown in Table 3) with their values, a model equation relating to the parameters for the CO_2 emissions can be derived as follows:

$$y = \sum_{i=0}^{11} x_i a_i \tag{2}$$

The F-value of 2017.19, obtained from analysis of variance (ANOVA), implies that the model is significant and there is only a 0.01% probability that F-value could occur due to noise (Table 2). Also, the value of R-square for this model is equal to 0.9991; showing the high accuracy of a mathematical model to predict response. The P-value less than 0.0500 indicates that the model terms are significant and values greater than 0.100 indicates the model terms are not significant. In this case, C, F, H, K, and L are significant model terms.

Normal probability plot (Fig. 2) for residuals shows the normality of the data. The points where are located close to the straight line in Fig. 2, have an insignificant effect while other parameters have a significant effect on response. This is obvious that negative effect also exists in the normal plot because increasing these parameters decreases the relevant response factor. From ANOVA (Table 2) and the normal plot (Fig. 2), it can be realized that F, L, C, H, and K parameters have significant effects on CO_2 emissions. Also, all the significant parameters have positive effects on CO_2 emissions.

The Pareto chart shows the important factors as well as factors' interactions quantitatively and provides graphical results of these ordered estimates, from largest to smallest. Pareto charts are

Table 3
Parameters of equation (2).

a_0	−756.50551	y	CO_2 emission
a_1	+2.45765E-004	x_1	Gas
a_2	−5.93493E-004	x_2	Oil products
a_3	+10.82118	x_3	Citizen rate
a_4	+7.12880E-004	x_4	Mean of incoming urban
a_5	−7.00175E-004	x_5	Mean of incoming rural
a_6	+0.51593	x_6	Consumption of energy
a_7	−2.03172	x_7	GDP
a_8	+2.90552	x_8	Non-oil GDP
a_9	+1.45099E-005	x_9	Number of vehicles
a_{10}	+0.46320	x_{10}	Cost of energy
a_{11}	+19.45189	x_{11}	FDI

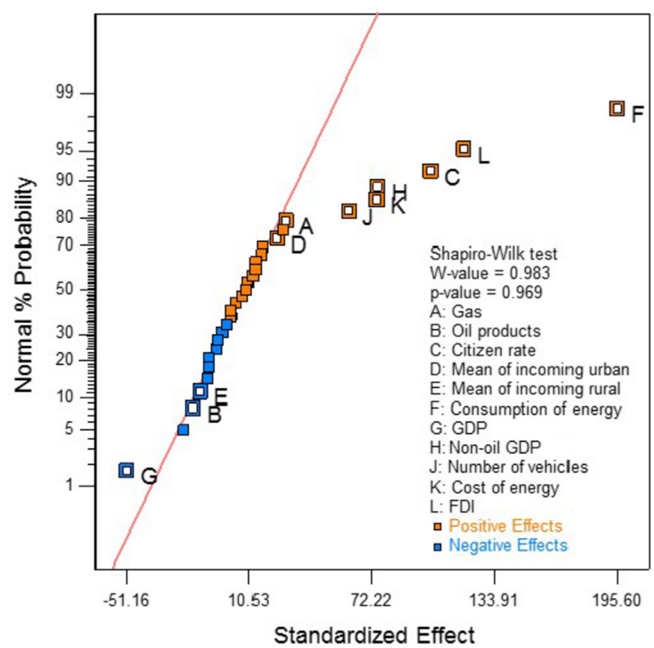

Fig. 2. Normal probability plot versus prediction of CO_2 emissions in Iran.

Table 2
Analysis of variance (ANOVA) results of the full factorial design model for CO_2 emissions.

Source	Sum of Squares	Degree of freedom	Mean Square	F-Value	P-value
Model	3.165E+006	11	2.878E+005	2017.19	<0.0001
A: Gas	70.20	1	70.20	0.49	0.4911
B: Oil products	25.72	1	25.72	0.18	0.6757
C: Citizen rate	861.45	1	861.45	6.04	0.0233
D: Mean of incoming urban	49.93	1	49.93	0.35	0.5608
E:Mean of incoming rural	16.13	1	16.13	0.11	0.7402
F: Consumption of energy	3188.53	1	3188.53	22.35	0.0001
G: GDP with oil	218.08	1	218.08	1.53	0.2306
H: non-oil GDP	472.66	1	472.66	3.31	0.0837
J: Number of vehicles	309.00	1	309.00	2.17	0.1566
K: Cost of energy	469.40	1	469.40	3.29	0.0847
L: FDI	1168.01	1	1168.01	8.19	0.0096

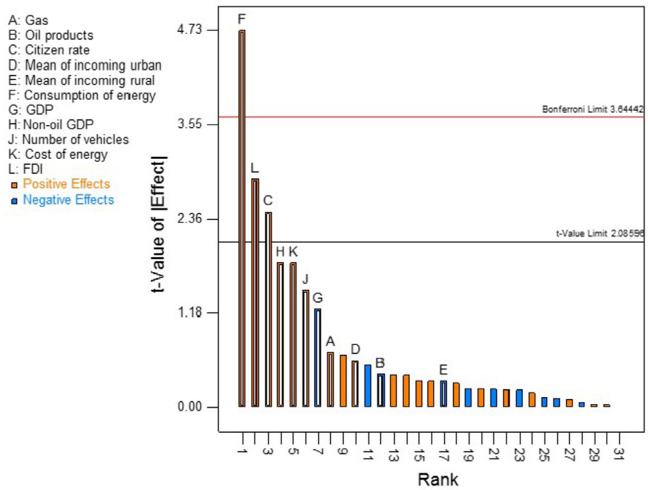

Fig. 3. Pareto chart versus prediction for CO_2 emission in Iran.

suitable to analyze variables which are sensitive to varying the responds or objective functions. Fig. 3 is depicted to show energy consumption, FDI, citizen rate, non-oil GDP, and cost of energy have the greatest effects on the CO_2 emissions. The number of vehicles, GDP, gas and oil consumptions have not significant effect on CO_2 emissions.

The results indicated a positive and significant relationship between citization rate and CO_2 emissions, suggesting higher urban population as well as further environmental pollution. Like many other countries, Iran's economy depends on fossil fuels. The fossil fuel especially oil exports accounted for about 82% of total Iran export revenues in 2016. Since oil export accounts a large share of total GDP in Iran, the GDP cannot represent actual economic growth while non-oil GDP (GDP without consideration of oil exporting(shows real GDP. Therefore, the GDP was considered both with or without consideration of oil exporting The results further indicated that GDP has not a significant effect on CO_2 emissions while non-oil GDP has a positive and significant effect on CO_2 emissions. It means actual development in industrial products leads to more CO_2 emissions. The results also showed that there is an appositive relationship between per capita emissions and FDI, suggesting that increasing trade volume leads to increase pollution. The energy consumption has also the significant and positive effect on per capita emissions. These results are in line with the finding of previous studies (Farhani et al., 2014b; Ozcan, 2013). Also, it seems energy cost has a few positive effects on CO_2 emissions.

4.2. Multivariate analysis

To conduct multivariate statistical analysis, data were projected to concise tabular format because this format is sufficient to gain information from all past data. The PLS model was created using the statistical data in order to evaluate correlations among the variables and determine the predictability of CO_2 emissions factors. It is necessary to mention that the input variables may be dependent on each other. The equation for PLS model is expressed as follows (Muteki and MacGregor, 2007; Sun et al., 2017):

$$X = TP^T + E \tag{3}$$

$$Y = TC^T + F \tag{4}$$

where X is a data matrix of $(m \times n)$ in which m (raw) and n (columns) represent the samples and variables, respectively. The matrix X can be decomposed into a loading matrix P $(m \times n)$ and a score matrix T $(m \times k)$. The number of principal components showing the systematic variation of the original data is given by K. The terms E and F stand for the residuals. Also, the same was observed for Y which decomposes into the matrix P and T (Muteki and MacGregor, 2007; Sun et al., 2017). The PLS method was used to build a model for both X- and Y-spaces. The Model Explorer tool in the ProMV software was applied to optimize the PLS unconstrained model by model inversion tools in order to predict the values of X-variables with a more precise estimate of CO_2 emissions.

The PLS model contains five-dimensional latent variable spaces; five dimensions in X-direction and one dimension in Y-direction. Overall R^2Y with a value of 0.995 is equal to R^2 in ordinary least squares regression and overall Q^2Y with a value of 0.975 shows predictability of models which was calculated by cross-validation (shown in Fig. 4a). Therefore, this model has excellent fit (R^2Y) and very high predictive performance (Q^2Y) for overall model.

R^2X can be also calculated especially when needing to estimate the X-variables to achieve a set of Y properties. Summarizing the data in five-dimensional space leads easier interpretation and the least deviations (equal 0.0001) between R^2Y and Q^2Y. Fig. 4b shows R^2X changes from one latent variable (R^2X is 0.6) to five latent variables (R^2X is 1). The higher components add incremental improvement to predictions of the specific X- and Y-variables. The least deviation and the highest correlation coefficients (0.999) happened with five latent variables.

The effect of different parameters including energy consumption, citizen rate, FDI, GDP and cost of energy on the response variable (CO_2 emissions) were investigated and the results are shown in Fig. 5. In other words, the latent variable approach was applied to determine an equation with adjusted coefficients and

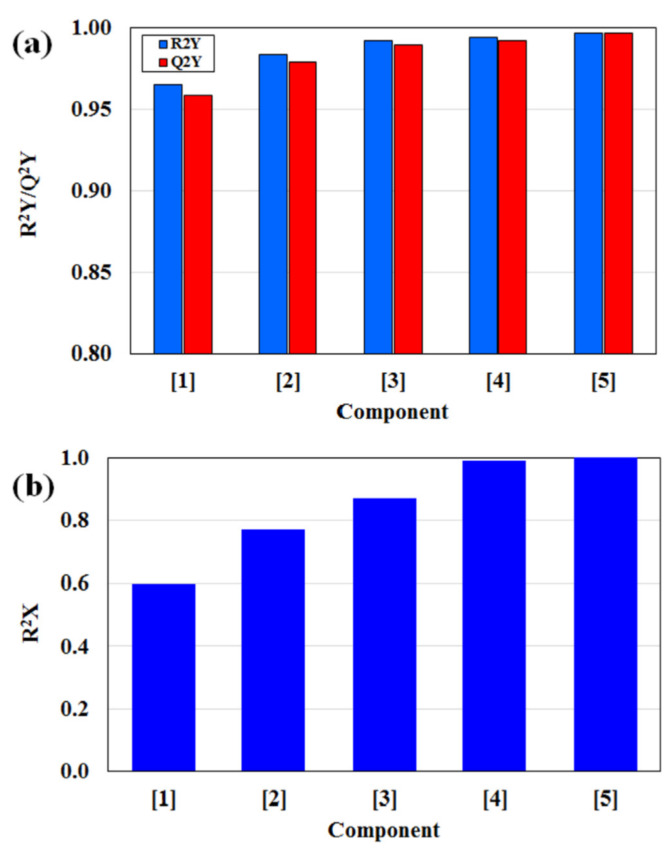

Fig. 4. a) Cumulative R^2Y and Q^2Y b) R^2X for the PLS model of historical data.

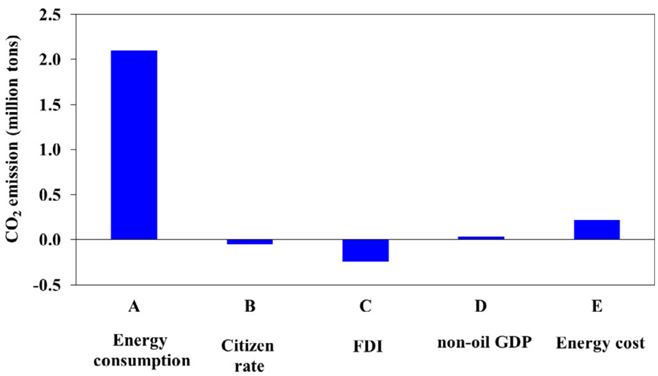

Fig. 5. Contribution of variables in CO_2 emissions from 1976 to 2016.

weights. The equation was able to analyze the effectiveness of parameters and their positive/negative impacts on CO_2 emissions. Collaborative plots show which variables cause differences in CO_2 emissions over the years. Based on Fig. 5, the participation of each variable on CO_2 emissions from the strongest (energy consumption = 2.1) to the weakest (non-oil GDP = 0.05) parameters was determined. As expected, the shares of variables were quite different at different times. The magnitude of the weight at a determined time for a certain variable shows the importance of variable at that point in time, for the first component (T[1]).

Since the energy consumption in the PLS model has the largest covariance, weights of positive correlation of these parameters were considered as the main factor in CO_2 emissions, while the parameters with the negative correlation have the minor effects on CO_2 emissions. According to Fig. 5, the energy cost has a positive correlation and the FDI has the highest negative correlation with other parameters during 1976–2016. Based on the results obtained here, it can be seen that the bar corresponding to the FDI is similar on the opposite side of energy cost; hence, FDI was negatively correlated with energy consumption and there is also a positive correlation link between the energy consumption and cost.

The PLS loading bi-plot is shown in Fig. 6 where all data is summarized by the first two model dimensions and shows the most important relationships among the variables and observations. The mean-centering is a standard preprocessing step for PLS; hence, the origin represents the average observations in the model. The high distance either among variables, or among variables and observations, shows less affected by each other so that the high distance indicates that variables are far from its relevant observation revealing those parameters have the least effects on CO_2 emissions. W^*_4 and W^*_5, c_4 and c_5, and W*c[4] and W*c[5] plots describe the X-space, Y-space, and links the X- and Y-spaces, respectively. In the T[4] and T[5] score plots, the dashed and filled ellipse line represents 95 and 99% confidence interval, respectively.

Fig. 6 indicates that citizen rate is located near CO_2 emissions whereas non-oil GDP is located in the opposite quadrant of plot and diagonal across the center. The energy cost is also located far from CO_2 emissions. The energy consumption and FDI are relatively close to the CO_2 emissions. This means that citizen rate rather than energy consumption and FDI, and these factors rather than the energy cost tend to increase CO_2 emissions. Moreover, Fig. 6 shows non-oil GDP, citizen rate, energy consumption and even energy cost are positively correlated with CO_2 emissions while FDI is negatively correlated. The literature survey on energy consumption and economic development has shown that energy has encouraging or curbing effect on economic growth. These investigations have led to different opinions. The first view which is recognized as the "neutrality hypothesis" offers that energy factor is neutral to growth, indicating the energy cost is a minor part of GDP, yielding minor effect. The other hypothesis which is recognized as "energy-led growth" offers the energy consumption is a determinative parameter to economic growth. Of course, the depending on energy consumption on economic development has affected the development state and economic structure of each country. As nations grow their economies, they move toward technologies that are less energy intensive (Alshehry and Belloumi, 2015). Although the importance of energy in terms of economic growth is evident, the

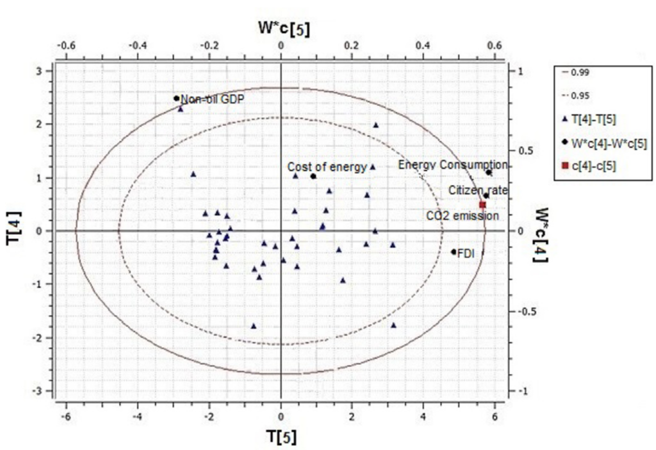

Fig. 6. Loading bi-plot for PLS of historical data.

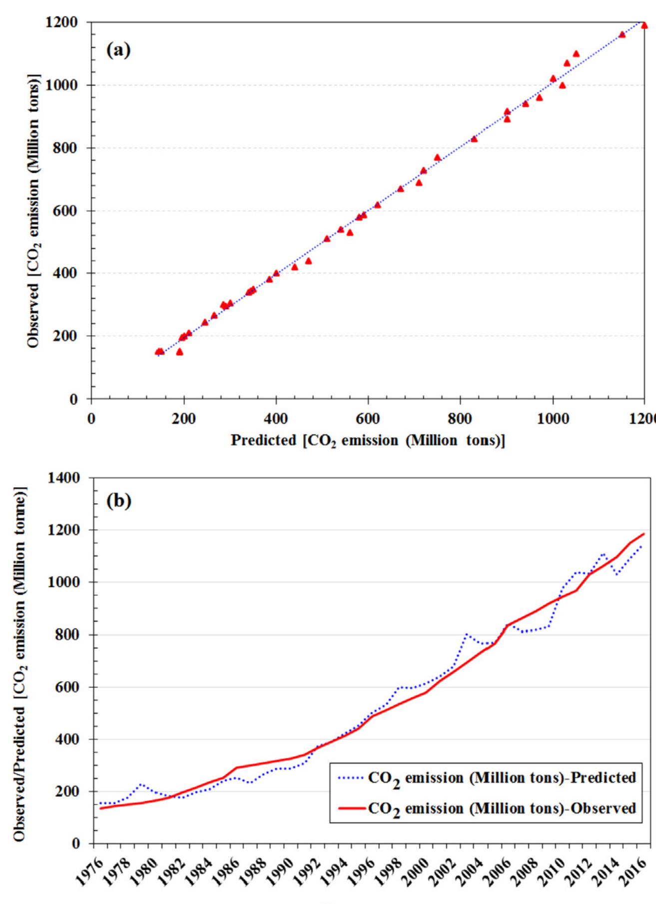

Fig. 7. a) Observed versus predicted data of CO_2 emissions. b) observed/predicted data of CO_2 emissions versus Year.

relationship between these two parameters or the direction of this relationship is still unclear. Their results of Figs. 5 and 6 show energy-led growth hypothesis is valid for Iran.

Fig. 7 compares the model-predicted and actual values of CO_2 emissions for the historical data (the “training” data set for this model). Fig. 7 shows that the PLS model can remarkably anticipate the CO_2 emissions using the novel equations by means of the SPE-X confidence restrictions. The perfect fitting of predicted data to observed data for CO_2 emissions revealed that prediction can happen across whole ranges of variables. The model predicted CO_2 emissions with high accuracy, indicating a linear function between CO_2 emissions and variable.

Fig. 8 shows the squared prediction error (SPE-X) for the historical data. The SPE-X values of all data points are approximately below the 99% confidence level in this model. Except for the year of 2016, most observations are below the 95% confidence limit, i.e., mostly follow the same correlation structure and are close to the model's plane. The relationships among the X-variables in the historical data are acceptable for predicting the CO_2 emissions factors.

Analysis of the model coefficients presents the size and direction of X-variables influence on Y-variables. From Fig. 9, it can be realized that the key variable for predicting the CO_2 emissions is energy consumption. CO_2 emissions are most correlated with energy consumption and consequently, FDI and energy cost. CO_2 emissions have the least correlated with citizen rate and non-oil GDP.

The score plot shown in Fig. 10 is used to analyze clustering and distributing of CO_2 emissions from 1976 to 2016. The purpose of cluster analysis, as a multivariate method, is minimizing differences in groups to reach more flexibility. Since in this study, there is a single group, only the data distributions were analyzed. The dashed and filled lines show 95 and 99% confidence level, respectively. From evaluation of Fig. 10, it can be realized that all data related to the CO_2 emissions distribution are around the common area of fourth and fifth components (T[4] and T[5]). Fig. 10 also indicates that the distribution of data has occurred properly within the specified area.

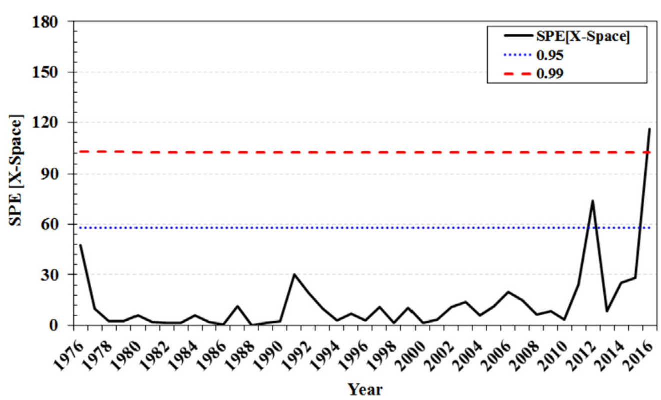

Fig. 8. Squared prediction error SPE-X values for the same observations.

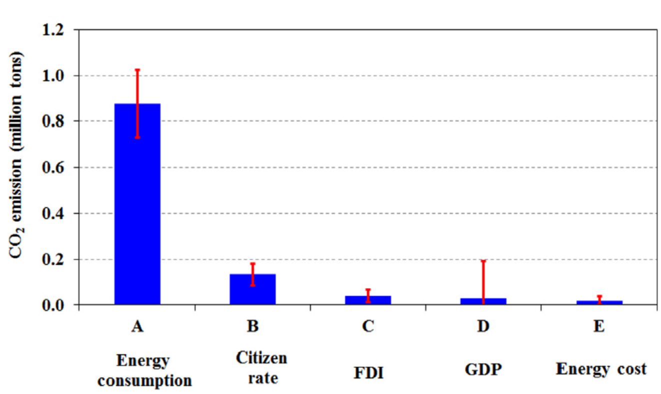

Fig. 9. Coefficient plots for CO_2 emissions, showing the influence (scaled magnitude and direction) of X-variables on Y-variables.

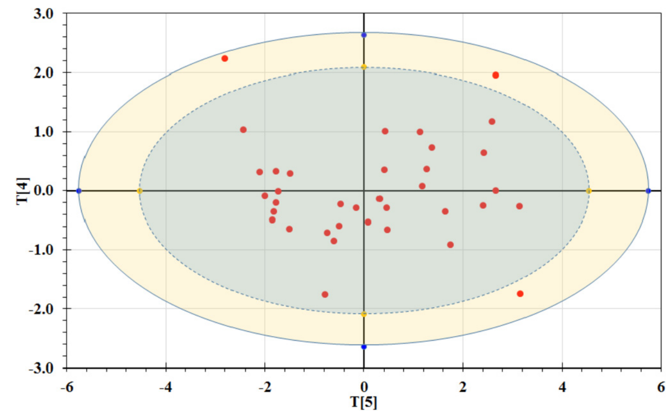

Fig. 10. Score plot showing model training data for CO_2 emissions (circle marker). The dashed and filled ellipse line represents 95 and 99% confidence interval, respectively.

From screening the results it can be realized that there is a positive relationship between energy consumption and per capita emission. This was also observed in numerous studies (Alam et al., 2012; Apergis and Payne, 2009; Chang, 2010; Halicioglu, 2009; Menyah and Wolde-Rufael, 2010b). 100% increase in the energy consumption shows 87% increment in CO_2 emissions. Therefore, the citizen rate has a significant and positive effect on per capita emission, indicating more urban populations, more CO_2 emissions. These results are in line with the results of other studies (de Freitas and Kaneko, 2011; Kasman and Duman, 2015). FDI is also negatively and significantly related to the CO_2 emissions suggesting that increasing foreign investment leads to decrease in environmental pollution. The results showed that 100% increase in foreign investment decreases 5% per capita emissions. In Iran, the rise in non-oil GDP and energy cost causes a slight increase in per capita CO_2 emissions.

This research was faced to some limitations such as restricted access to resources (data), limited date ranges, and unknown variables. There may be other factors that have not been taken into consideration. Also, the results of this research could be used more extensively by increasing the evaluation period and considering more factors.

4.3. Policy implication

In the last decades, Iran's economy has grown slightly, while total energy consumption and CO_2 emission have rapidly increased. The energy consumption and non-oil GDP have a direct effect on emissions. In the point of economic growth, Iran is capable to provide the energy from the resources with fewer emissions instead of conventional fossil fuels. Furthermore, in last decade, Iran vigorously develops clean energies and transforms coal and oil to natural gas rapidly. But in the fields of energy resources, renewable energies have not developed properly and there is a definite need to make enhancement in this issue. Also, the technology with high energy efficiency and the implementation of energy conservation policies can make economic development with less production of carbon. The results indicated that FDI has reduced the emissions which are interesting results. The foreign

investment in Iran is almost along with the use of technology with more energy efficiency; therefore, although FDI commonly is on the industrial section but due to using of higher technology does not raise the CO_2 emissions. Hence, investment of energy efficient system, energy saving technologies, and policies for emission reduction will be a feasible policy for Iran without deteriorating economic development.

In addition, there is a growing trend of urbanization in Iran, where the level of urbanization has enhanced from 45% to 75% during 40 years. The urbanism culture drives human to more energy. Also, the results presented here showed that increasing the cost of energy cannot decrease the use of energy and consequently the CO_2 emissions. As a result, green urbanization, social development, cultural program for increasing the knowledge and sensitivity of people to the energy issue can be suggested to reduce emission in Iran.

5. Conclusion

The status of energy consumption through all proxies in Iran was reviewed. Afterward, the links among CO_2 emissions, energy consumption, gas consumption, oil product, FDI, GDP, non-oil GDP, citizen rate, energy cost, number of vehicles, and mean incoming urban and rural for Iran over the period of 1976–2016 was explored. Particularly, the paper attempted to test the experimental design for all factors using full factorial methods. The results suggested a linear relationship between CO_2 emissions and five variables including energy consumption and cost, citizen rate, non-oil GDP, and FDI. In addition, based on the factorial results, the statistically significant factors were investigated by the latent variable model, and all data were applied in the building of PLS model, and also latent variable model was optimized by model inversion. The latent variable model can model the non-linear relationship between variables and highly correlated data effectively. The results based on both factorial and PLS suggested a positive relationship between citizen rate and CO_2 emissions. Also, in Iran as a one of the country with exporting of oil and gas, GDP has not a significant effect on CO_2 emissions while non-oil GDP has a positive relationship with environmental pollution. In line with other researchers, energy consumption has the most effect on CO_2 emissions. In addition, there is a close and negative relation between FDI and CO_2 emissions. Although energy cost has a positive effect on CO_2 emissions, while the severity of the effect is low.

References

Ahmad, N., Du, L., Lu, J., Wang, J., Li, H.-Z., Hashmi, M.Z., 2017. Modelling the CO2 emissions and economic growth in Croatia: is there any environmental Kuznets curve? Energy 123 (Suppl. C), 164–172.

Alam, M.J., Begum, I.A., Buysse, J., Van Huylenbroeck, G., 2012. Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. Energy Pol. 45, 217–225.

Alshehry, A.S., Belloumi, M., 2015. Energy consumption, carbon dioxide emissions and economic growth: the case of Saudi Arabia. Renew. Sustain. Energy Rev. 41, 237–247.

Ang, J.B., 2007. CO 2 emissions, energy consumption, and output in France. Energy Pol. 35 (10), 4772–4778.

Ang, J.B., 2008. Economic development, pollutant emissions and energy consumption in Malaysia. J. Pol. Model. 30 (2), 271–278.

Apergis, N., Payne, J.E., 2009. CO2 emissions, energy usage, and output in Central America. Energy Pol. 37 (8), 3282–3286.

Chang, C.-C., 2010. A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China. Appl. Energy 87 (11), 3533–3537.

Coondoo, D., Dinda, S., 2002. Causality between income and emission: a country group-specific econometric analysis. Ecol. Econ. 40 (3), 351–367.

de Freitas, L.C., Kaneko, S., 2011. Decomposition of CO 2 emissions change from energy consumption in Brazil: challenges and policy implications. Energy Pol. 39 (3), 1495–1504.

Dinda, S., Coondoo, D., 2006. Income and emission: a panel data-based cointegration analysis. Ecol. Econ. 57 (2), 167–181.

Eriksson, L., Johansson, E., Kettapeh-Wold, S., Wold, S., 1999. Introduction to Multi- and Megavariate Data Analysis Using Projection Methods (PCA & PLS). Umetrics, Umeå.

Farhani, S., Mrizak, S., Chaibi, A., Rault, C., 2014a. The environmental Kuznets curve and sustainability: a panel data analysis. Energy Pol. 71 (Suppl. C), 189–198.

Farhani, S., Mrizak, S., Chaibi, A., Rault, C., 2014b. The environmental Kuznets curve and sustainability: a panel data analysis. Energy Pol. 71, 189–198.

Friedlingstein, P., Andrew, R.M., Rogelj, J., Peters, G.P., Canadell, J.G., Knutti, R., Luderer, G., Raupach, M.R., Schaeffer, M., van Vuuren, D.P., Le Quere, C., 2014. Persistent growth of CO2 emissions and implications for reaching climate targets. Nat. Geosci. 7 (10), 709–715.

Halicioglu, F., 2009. An econometric study of CO 2 emissions, energy consumption, income and foreign trade in Turkey. Energy Pol. 37 (3), 1156–1164.

Hoffmann, R., Lee, C.-G., Ramasamy, B., Yeung, M., 2005. FDI and pollution: a granger causality test using panel data. J. Int. Dev. 17 (3), 311–317.

Kasman, A., Duman, Y.S., 2015. CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ. Modell. 44, 97–103.

Lotfalipour, M.R., Falahi, M.A., Ashena, M., 2010. Economic growth, CO 2 emissions, and fossil fuels consumption in Iran. Energy 35 (12), 5115–5120.

MacGregor, J.F., Bruwer, M.J., Miletic, I., Cardin, M., Liu, Z., 2015. Latent variable models and big data in the process industries. IFAC-PapersOnLine 48 (8), 520–524.

Mazandarani, A., Mahlia, T., Chong, W., Moghavvemi, M., 2011. Fuel consumption and emission prediction by Iranian power plants until 2025. Renew. Sustain. Energy Rev. 15 (3), 1575–1592.

Menyah, K., Wolde-Rufael, Y., 2010a. CO 2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Pol. 38 (6), 2911–2915.

Menyah, K., Wolde-Rufael, Y., 2010b. Energy consumption, pollutant emissions and economic growth in South Africa. Energy Econ. 32 (6), 1374–1382.

Merican, Y., 2007. Foreign direct investment and pollution in five Asean nations. Inter. J. Econ. Manag. 1 (2), 245–261.

Muteki, K., MacGregor, J.F., 2007. Multi-block PLS modeling for L-shape data structures with applications to mixture modeling. Chemom. Intell. Lab. Syst 85 (2), 186–194.

Ozcan, B., 2013. The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: a panel data analysis. Energy Pol. 62, 1138–1147.

Pao, H.-T., Tsai, C.-M., 2011. Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy 36 (1), 685–693.

Razavi, S.M.R., Rezakazemi, M., Albadarin, A.B., Shirazian, S., 2016. Simulation of CO 2 absorption by solution of ammonium ionic liquid in hollow-fiber contactors. Chem. Eng. Process: Process Intensification 108, 27–34.

Rezakazemi, M., Ebadi Amooghin, A., Montazer-Rahmati, M.M., Ismail, A.F., Matsuura, T., 2014. State-of-the-art membrane based CO_2 separation using mixed matrix membranes (MMMs): an overview on current status and future directions. Prog. Polym. Sci. 39 (5), 817–861.

Rezakazemi, M., Heydari, I., Zhang, Z., 2017. Hybrid systems: combining membrane and absorption technologies leads to more efficient acid gases (CO2 and H 2 S) removal from natural gas. J. CO2 Util. 18, 362–369.

Rezakazemi, M., Niazi, Z., Mirfendereski, M., Shirazian, S., Mohammadi, T., Pak, A., 2011. CFD simulation of natural gas sweetening in a gas–liquid hollow-fiber membrane contactor. Chem. Eng. J. 168 (3), 1217–1226.

Rezakazemi, M., Sadrzadeh, M., Matsuura, T., 2018. Thermally stable polymers for advanced high-performance gas separation membranes. Prog. Energy Combust. Sci. 66, 1–41.

Samsami, R., 2013. Application of ant colony optimization (ACO) to forecast CO2 emission in Iran. Bull. Env. Pharmacol. Life Sci. 2 (6), 95–99.

Shirazian, S., Marjani, A., Rezakazemi, M., 2011. Separation of CO2 by single and mixed aqueous amine solvents in membrane contactors: fluid flow and mass transfer modeling. Eng. Comput. 28 (2), 189–198.

Soroush, E., Shahsavari, S., Mesbah, M., Rezakazemi, M., Zhang, Z., 2017. A robust predictive tool for estimating CO 2 solubility in potassium based amino acid salt solutions. Chin. J. Chem. Eng.

Soytas, U., Sari, R., 2006. Energy consumption and income in G-7 countries. J. Pol. Model. 28 (7), 739–750.

Soytas, U., Sari, R., Ewing, B.T., 2007. Energy consumption, income, and carbon emissions in the United States. Ecol. Econ. 62 (3), 482–489.

Sun, F., Xu, B., Zhang, Y., Dai, S., Shi, X., Qiao, Y., 2017. Latent variable modeling to analyze the effects of process parameters on the dissolution of paracetamol tablet. Bioengineered 8 (1), 61–70.

Wang, K., Zhu, B., Wang, P., Wei, Y.-M., 2016. Examining the links among economic growth, energy consumption, and CO2 emission with linear and nonlinear causality tests. Nat. Hazards 81 (2), 1147–1159.

Xing, Y., Kolstad, C.D., 2002. Do lax environmental regulations attract foreign investment? Environ. Resour. Econ. 21 (1), 1–22.

Yacoub, F., MacGregor, J.F., 2004. Product optimization and control in the latent variable space of nonlinear PLS models. Chemom. Intell. Lab. Syst 70 (1), 63–74.

Zamani, M., 2007. Energy consumption and economic activities in Iran. Energy Econ. 29 (6), 1135–1140.

Zarsky, L., 1999. Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment. Foreign Direct Invest. Environ. 13 (8), 47–74.